

Determining Molar Mass by Freezing Point Depression

PURPOSE

- Compare freezing points of a pure solvent and a known solution of the solvent to determine the change in freezing point, ΔT_f .
- Calculate the molal freezing point depression constant (K_f) for the solvent.
- Determine the molar mass of an unknown solute using data from the preceding procedures.

INTRODUCTION

A **solution** is a homogeneous mixture of substances, comprised of at least two components, the major component being the solvent and the minor the solute. The **solvent** is the component that defines the phase of a solution; it is the material into which the solute is introduced. The **solute** is the substance that dissolves in a solvent to form a solution. A solution can be made from any combination of the phases of matter. In this lab, two solids are mixed together, then melted to complete the solution process.

There are a number of ways of expressing concentration quantitatively, but the ones commonly used in AP Chemistry are molarity (M), molality (m), mole fraction (χ), and mass percent. These are defined as follows:

$$M = \frac{\text{mol solute}}{\text{L solution}}$$

$$m = \frac{\text{mol solute}}{\text{kg solvent}}$$

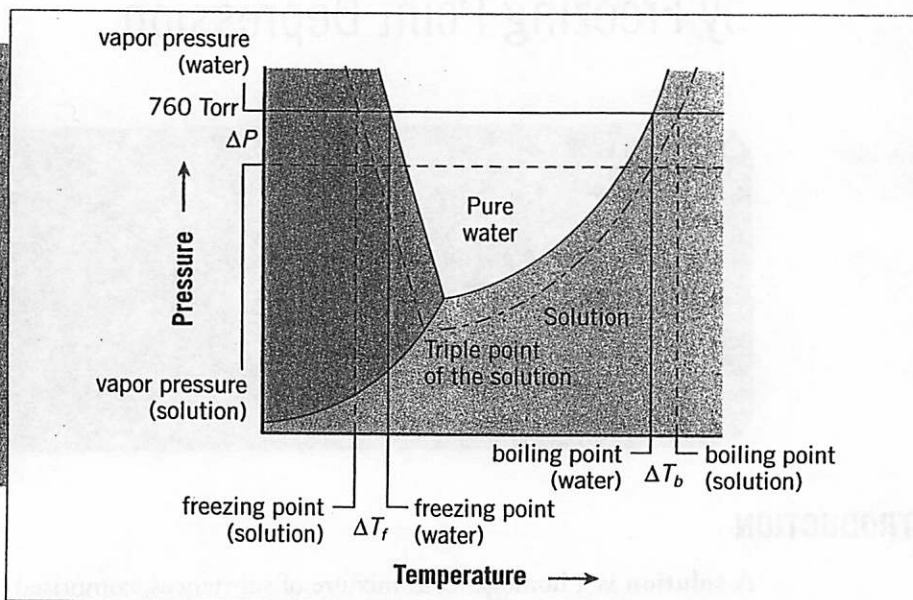
$$\chi = \frac{\text{mol solute}}{(\text{total number of mol solute} + \text{mol solvent})}$$

$$\text{mass \%} = \frac{\text{mass solute}}{(\text{total mass solute} + \text{solvent})} \times 100\%$$

Because volume varies as temperature varies, any concentration measure that includes volume in its definition is temperature dependent. Therefore, a stated molarity, for instance, must include the temperature at which the solution was measured. Ratios that compare only moles or mass are not temperature dependent, because those quantities do not vary as the temperature does.

Colligative properties are a set of characteristics that differ for a pure solvent and a solution of the solvent. The presence of particles of solute in the solvent interferes with the normal behavior of the solvent, especially the characteristic of vapor pressure. It is not important what the chemical composition or size of the solute particles may be, just that they are in solution with the solvent. It is the *quantity of particles* in solution that does change the behavior of the solvent, so a measure of concentration occurs in each of the equations that describe colligative properties. These equations describe the behavior of dilute solutions best, because the behavior of dilute solutions is closest to ideal. At higher concentrations the solutions no longer behave in an ideal fashion.

Figure 14.1
This generic phase diagram illustrates change in three colligative properties—vapor pressure (ΔP), freezing point (ΔT_f), and boiling point (ΔT_b)—for pure water vs. an aqueous solution.



The colligative property investigated in this lab is that of **freezing point depression**. The presence of solute particles extends the temperature range over which the solvent remains liquid, so the boiling point of the solution is higher than that of the solvent, whereas the freezing point of the solution is lower than that of the solvent. The equation that describes the change in freezing point is

$$\Delta T_f = iK_f m$$

where i = number of moles of solute particles in solution (van't Hoff value)
 K_f = molal freezing point constant for the solvent
 m = concentration in molality (used since temperature varies)

Procedure Preview In this experiment, you will establish the freezing point of a pure solvent. By contaminating the pure solvent with a known quantity of a known solute, you can formulate a known solution. Then, by determining the freezing point of the known solution and comparing it to the freezing point of the pure solvent, you will be able to calculate the change in freezing point, ΔT_f , and the freezing point depression constant, K_f , of the solvent. Finally, by making a solution of a fresh sample of the solvent with an unknown solute, and measuring its freezing point, you can calculate the molar mass of the unknown solute. You will make use of the following equations:

$$\Delta T_f = iK_f m$$

$$m = \frac{\text{mol solute}}{\text{kg solvent}}$$

$$\text{mol solute} = \frac{\text{g solute}}{MM_{\text{solute}}}$$

By substituting, you can derive this relationship:

$$MM_{\text{solute}} = \frac{iK_f g_{\text{solute}}}{\text{kg solvent } \Delta T_f}$$

MATERIALS

- medium test tubes
- lauric acid (dodecanoic acid, $\text{CH}_3(\text{CH}_2)_{10}\text{COOH}$)
- palmitic acid (hexadecanoic acid, $\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$)
- unknown molecular solute
- thermometer (or thermoprobe with CBL or computer)
- hot water bath (*Lab Hint:* start the bath *now* because it will be used several times during the experiment. One hundred mL of tap water in a 250-mL beaker is more than enough.)

Optional

- ring stand and clamp

PROCEDURE

I. Establishing the freezing point of the pure solvent

- Step A** Weigh out >5 g of lauric acid. Although your quantity need not be exactly 5 g, it is important to record how much you do use.
- Step B** Place the lauric acid into a medium test tube.
- Step C** Transfer the test tube to the hot water bath, submerging the closed end of the tube into the hot water.
- Step D** When the lauric acid has melted completely, move the test tube out of the hot water bath. You could clamp the test tube to a ring stand, but it may be just as convenient to hold it.
- Step E** Place a thermometer (or thermoprobe) into the solvent.
- Step F** Read the temperature of the liquid lauric acid every 15 seconds for 5 minutes, or until the temperature has not changed for two minutes. Record the temperature to 0.1°C . Do not use the temperature-sensing device to stir, but move it often so that the temperature measured is that of the center of a well-mixed liquid solution.

PROCEDURE (continued)

II. Establishing K_f of the solvent using known solute

- Step A** Weigh out <0.5 g of palmitic acid. Although the quantity need not be exactly 0.5 g, it is important to record exactly how much you measure out.
- Step B** Add the palmitic acid directly into the test tube that contains the lauric acid used in Procedure I above.
- Step C** Transfer the test tube to the hot water bath, submerging the closed end of the tube until the solution melts completely.
- Step D** Establish the freezing point of the solution, as you did for the pure solvent.
- Step E** Be sure to clean the temperature-sensing device by rinsing it in hot water, then wiping it carefully with a paper towel.

III. Determining M_M of the unknown solute

- Step A** Prepare a new test tube of solvent by weighing out a fresh sample of >5 g of lauric acid.
- Step B** Weigh out <0.5 g of an unknown solute, to be specified by your instructor. Add the solute to the lauric acid in the new test tube.
- Step C** Melt the solution completely in the hot water bath, taking temperature readings every 15 seconds, as in the previous procedures, until the freezing point of the solution of lauric acid + unknown solute is established.
- (*Caution:* Do *not* pour hot solutions into the sink! They will solidify in the trap and block the drain. Ask your instructor for explicit directions on how to dispose of the waste.)

Calculations

1. Using a graphing program, draw graphs of the three cooling curves (pure lauric acid, lauric acid + palmitic acid, lauric acid + unknown solute). Be sure to plot temperature on the y-axis and time on the x-axis.
2. Find a freezing point for each curve by drawing two lines—one tangential to the curve where it represents the liquid cooling rapidly, and one tangential to the curve where it represents the liquid-solid slurry (the plateau of the graph). The point of intersection of these two tangents is the freezing point.
3. Determine ΔT_f by comparing the cooling curves for pure lauric acid and the lauric acid-palmitic acid solution.
4. Use ΔT_f and m (the molality) to calculate the K_f (molal freezing point depression constant) for the solvent lauric acid.
5. Determine ΔT_f by comparing the cooling curves for the pure lauric acid and the solution of lauric acid + unknown solute.
6. Use this ΔT_f and the K_f established in Calculation 4 to figure the MM of the unknown solute.

Post-Lab Questions

1. If the unknown solute were benzoic acid, what would be the percent error in the calculated MM ? Look up the term **dimerization** and comment on its application in this lab.
2. Use the *Merck Index*, the *CRC Handbook of Chemistry and Physics*, *Lange's Handbook of Chemistry*, or another reference source to find a published value for the freezing point of lauric acid. Calculate percent error. Comment on possible sources of error. Would an error in establishing the freezing point of lauric acid affect the results of your attempt to find the MM of the unknown?
3. In each of the following cases, explain your reasoning thoroughly, using equations if necessary. What would have happened to your calculated MM if you had
 - a. spilled some lauric acid before finding the freezing point?
 - b. spilled some palmitic acid before adding it to the lauric acid?
 - c. failed to clean lauric acid-palmitic acid solution from the temperature-sensing device before measuring the lauric acid-unknown solution?